NASA TECHNICAL NOTE

NASA TN D-5931

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NASA TN D-5931

AIR PERMEABILITY STUDIES OF A LIGHTWEIGHT COATED FABRIC SUBJECTED TO UNIAXIAL TENSILE LOADS WITH AND WITHOUT PRIOR CYCLING

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • AUGUST 1970

1. Report No.
NASA TN D-5931

2. Government Accession No.

3. Recip

4. Title and Subtitle
AIR PERMEABILITY STUDIES OF A LIGHTWEIGHT COATED FABRIC SUBJECTED TO UNIAXIAL TENSILE LOADS WITH AND WITHOUT PRIOR CYCLING

5. Report Date
August 1970

6. Performing Organization Code

7. Author(s)
Jerry W. Deaton

8. Performing Organization Report No.
L-6997

9. Performing Organization Name and Address
NASA Langley Research Center
Hampton, Va. 23365

10. Work Unit No.
124-08-18-04

11. Contract or Grant No.

12. Sponsoring Agency Name and Address
National Aeronautics and Space Administration
Washington, D.C. 20546

13. Type of Report and Period Covered
Technical Note

14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

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17. Key Words (Suggested by Author(s))
Permeability
Porosity
Coated fabrics
Inflatable structures
Nonmetallic materials

18. Distribution Statement
Unclassified – Unlimited

19. Security Classif. (of this report)
Unclassified

20. Security Classif. (of this page)
Unclassified

21. No. of Pages
22

22. Price*
$3.00

*For sale by the Clearinghouse for Federal Scientific and Technical Information
Springfield, Virginia 22151

AIR PERMEABILITY STUDIES OF A LIGHTWEIGHT COATED FABRIC SUBJECTED TO UNIAXIAL TENSILE LOADS WITH AND WITHOUT PRIOR CYCLING

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SUMMARY

The air permeability of a particular lightweight fluorocarbon rubber-coated high-temperature nylon fabric as determined experimentally from strip specimens at room temperature while subjected to uniaxial tension are presented and discussed. Strip specimens were load cycled at 0.25, 0.50, and 0.75 of the fabric strength for 10 and 100 cycles for comparison with the air permeability obtained during the initial loading of similar specimens. The results demonstrate that the coating remains effective with regard to air permeability for stresses to about 0.90 of the ultimate fabric strength for the initial tensile loading for both the warp and fill directions. However, the coating became ineffective for the specimens subjected to cyclic tensile loads and the resulting air permeability was found to be dependent on both the magnitude and the number of cyclic loadings. The air permeability of the cyclic-loaded specimens were shown to be different in the warp and fill directions and the differences are attributed to basic differences in the stress-elongation behavior as well as to differences in the yarn twist for the warp and fill directions.

INTRODUCTION

Lightweight coated fabrics are currently being considered for various aerospace structures that are deployable. Applications include inflatable structures such as decelerators and landing bags as well as parawings. Research has indicated that during deployment, the fabric structures undergo erratic motions which result in high stresses that affect the design parameters of the structure.

One parameter, air permeability, is of particular importance for inflatable structures such as the attached inflatable decelerator (AID). The AID is a lightweight ram-air-inflated canopy that may attach directly to a planetary payload and it is designed to be deployed at supersonic speeds. In most decelerator applications, the fabric is biaxially loaded and in the case of supersonic deceleration, the fabric is exposed to elevated temperatures for short periods of time. Design information concerning the air permeability of lightweight coated fabrics subjected to these conditions is lacking in the literature. However, some effects of biaxial loads on the air permeability of several coated and uncoated fabrics at room temperature are presented in reference 1. Recent wind-tunnel tests demonstrated that increases in the fabric air permeability of AID models from 0.02 to 10.0 $ft^3/min/ft^2$ (0.10 to 50.8 $dm^3/s/m^2$) resulted in excessive fabric flutter and drastically reduced measured drag force. (See ref. 2.)

The present work is concerned with the initial results of a continuing program to determine the effects of various loadings on the air permeability of a lightweight coated fabric being used in an AID development program. (See ref. 3.) These initial results deal with the effects at room temperature of uniaxial tensile loading and load cycling on the air permeability of a particular fluorocarbon rubber-coated lightweight high-temperature nylon fabric.

SYMBOLS

The units used for the physical quantities in this paper are given both in U.S. Customary Units and in the International System of Units (SI). Factors relating the two systems are given in reference 4, and those used in the present investigation are presented in the appendix.

N	applied uniaxial tensile load, lbf/in. (N/m)
N_{fc}	fill direction uniaxial tensile cyclic load, lbf/in. (N/m)
N_{fu}	fill direction uniaxial tensile strength, lbf/in. (N/m)
N_{wc}	warp direction uniaxial tensile cyclic load, lbf/in. (N/m)
N_{wu}	warp direction uniaxial tensile strength, lbf/in. (N/m)
P	air permeability at 0.5 in. H_2O (124 N/m^2), $ft^3/min/ft^2$ ($m^3/s/m^2$)
ϵ	fabric unit elongation, percent

Subscripts:

f	fill

w warp

u ultimate

TEST SPECIMENS AND METHOD OF TESTING

The lightweight coated fabric used for the present investigation is similar to that used in reference 2 and consists of a plain-weave heat-calendered high-temperature nylon fabric having a single coat of fluorocarbon rubber applied to one side. Other details of the fabric are given in table I. Figure 1 shows a photomicrograph of the coated fabric material. The fabric has one set of yarns with considerable crimp whereas the other set of yarns is more nearly straight. The crimped yarns are oriented in the fill direction and appear in figure 1 as the darker colored yarns, whereas the more nearly straight yarns are oriented in the warp direction and appear as the lighter colored yarns. A close examination of the photomicrograph indicates that the warp yarns have some degree of twist that is lacking in the fill yarns. One set of specimens was made with the warp yarns and one set was made with the fill yarns oriented in the longitudinal direction of the specimens. Hereinafter, the specimens with the warp yarns oriented in the longitudinal direction are referred to as warp specimens and the specimens with the fill yarns oriented in the longitudinal direction are referred to as fill specimens.

Plain strips of the fabric were tested. General details of the strip specimens are shown in figure 2. Strip specimens were 3 inches (7.6 cm) wide and approximately 20 inches (51 cm) long. The specimens were clamped in smooth-faced steel jaws that were 3 inches (7.6 cm) wide by 2 inches (5.1 cm) deep. The strip passed through the jaws, around a 0.13-inch-diameter (0.3-cm) brass pin, and then back through the jaws. (See fig. 2.) The distance between grips was initially 9 inches (23 cm) without slack in the specimen. Figure 3 shows the setup for tensile loading of the fabric specimens.

Five warp and five fill specimens were tested to failure to determine the ultimate uniaxial tensile strength of the fabric. The average values obtained from these tests appear in table I. Additional specimens were tested to obtain stress-elongation properties for cycled and noncycled warp and fill specimens.

Warp and fill specimens were subjected to uniaxial tensile cyclic loads of 0.25, 0.50, and 0.75 of the ultimate uniaxial tensile strength of the fabric for either 10 or 100 cycles. For each orientation of the fabric, cyclic load, and number of loading cycles, three specimens were tested for a total of 36 cyclic-load specimens. The test procedure was as follows: A warp or fill specimen was placed in a model 4301 Gurley permeameter and the air permeability determined at a pressure differential across the specimen of 0.5 in. H_2O (124 N/m^2). The specimen was then placed in the grips of the screw-driven testing machine shown in figure 3 and load cycled for either 10 or 100 cycles. The testing machine was set to cycle automatically between a minimum and maximum value of indicated load at a crosshead speed of 0.5 in./min (210 μm/s). In all cases the minimum load value was zero whereas the maximum load value was either 0.25, 0.50, or 0.75 of the ultimate tensile strength of the fabric given in table I. After the required number of loading cycles had been obtained, the grips and specimen were removed from the testing machine carefully; thus stretching or flexing of the specimen was not significant. The grips were then placed in a horizontal screw-driven testing instrument. (See fig. 4.) The permeameter was positioned to measure the air permeability of the central area of the specimen (see figs. 2 and 4) prior to its being loaded. After this measurement was obtained, the specimen was loaded slowly until the desired load was obtained, and then the permeameter was leveled and adjusted until the upper clamping ring was parallel to and just barely in contact with the upper surface of the specimen. This procedure was necessary to prevent the introduction of out-of-plane loads into the test specimen. The lower clamping ring of the permeameter was carefully engaged with the lower surface of the specimen, and the air-permeability measurement was obtained. The lower clamping ring was then disengaged and the next higher desired load was applied to the specimen. This procedure was repeated for increasing loads (without unloading) until the specimen failed.

In addition to the permeability tests of specimens with prior cyclic loading histories, two warp and two fill specimens without previous loading histories were tested to failure by using the horizontal screw-driven instrument shown in figure 4. Air-permeability measurements were obtained for these specimens while subjected to uniaxial tension by use of the same procedure as for the cyclic-load specimens previously described.

All specimens were conditioned at 72° F (295 K) and approximately 50-percent relative humidity for at least 48 hours prior to being tested, and all air-permeability measurements were made under these environmental conditions. However, when the specimens were load cycled by using the testing machine shown in figure 3, it was necessary to do this part of the test at room temperature (approximately 75° F (297 K)) and without humidity control. It is estimated that the relative humidity ranged between 40 percent and 80 percent over a 6-month period which encompasses the period of time for the test program. The length of time at these conditions depended on the magnitude of the load and the number of load cycles. The maximum time at these conditions for a given specimen was 3.25 hours.

RESULTS AND DISCUSSION

The measured values of air permeability are given in tables II and III and are plotted in figures 5 and 6. The ordinates of these figures give the air permeability measured at 0.5 in. H_2O (124 N/m^2) pressure differential and the abscissas indicate the load level at which these measurements were made. The dashed curves (located in the lower right-hand corner of these figures) represent the average of the air-permeability data obtained from the two warp and two fill specimens with no previous loading histories. These data show that the coating remains effective with regard to air permeability for stresses to about 0.90 of the ultimate fabric tensile strength. The symbols represent the average of the data obtained from the three specimens for each cyclic load and the lines drawn through the symbols and parallel to the ordinate indicate the range in values of the measured air permeability. It is clear from figures 5 and 6 that considerable data scatter is present in the measured air-permeability values for the relatively small test specimens used in this investigation.

In figure 5, it is shown that the air permeability for the cycled warp specimens increases with applied load and magnitude of the cyclic load. This condition is particularly true for the two larger cyclic loads $\left(\frac{N_{wc}}{N_{wu}} = 0.75 \text{ and } 0.50\right)$ and to a lesser extent for the smaller cyclic load $\left(\frac{N_{wc}}{N_{wu}} = 0.25\right)$. This condition is apparently due to the inability of the thin coating to sustain a few repeated load cycles. Comparison of the cyclic-load data with the data for the specimens with no previous loading histories (dashed curves) indicates that most of the damage to the coating and the consequent increased air permeability occur within the first ten loading cycles. This trend was also observed for the fill specimens.

In figure 6, it is seen that the air permeability for the cycled fill specimens increases with applied load but to a lesser degree than that for the warp specimens. The air permeability is also shown to increase with the magnitude of the cyclic load although in figure 6 the three curves are approaching a similar air-permeability value at the higher applied loads.

Comparison of figures 5 and 6 indicates that, in general, after cycling and at low values of applied load, the fill specimens exhibit larger values of air permeability than do the corresponding warp specimens whereas the warp specimens have the larger values of air permeability at the intermediate and high values of applied load. The air permeability, as indicated by the permeameter, is assumed to be dependent only on the total number and size of openings between adjacent warp and fill yarns. The permeameter has a fixed test area of 4 in^2 (26 cm^2); therefore, the number of openings observed by the permeameter are related to the strain level of the specimen. The number of openings (to the nearest 100) at stresses corresponding to 0, 0.25, 0.50, and 0.75 of the fabric strength are given in the following table:

$\frac{N}{N_u}$	Number of openings	
	Warp	Fill
0	23 700	23 700
.25	23 500	22 900
.50	23 100	22 300
.75	22 300	21 600

Examination of the table shows that for specimens subjected to uniaxial load, the number of openings observed by the permeameter is less for the fill specimens than for the warp specimens. Therefore, in order for the fill specimens to exhibit larger air permeability after cycling and at the lower applied loads than the corresponding warp specimens, the size of the openings must necessarily be larger for the fill specimens. The stress-unit elongation curves in figures 7 and 8 indicate that large differences in these properties exist between the warp and fill directions of the coated fabric. The curve for the noncycled warp specimen (fig. 7) indicates a near-linear stress-unit elongation behavior up to a load corresponding to about 0.30 of the ultimate fabric tensile strength, at which point the specimen starts to elongate more rapidly with increasing load. However, the noncycled fill specimen (fig. 8) exhibits a very nonlinear behavior up to a load corresponding to about 0.10 of the fill direction ultimate fabric tensile strength; this behavior is probably due to the necessity of straightening the crimp (see fig. 1) in the fill yarns. Comparison of these curves at a stress equal to 0.25 of the fabric tensile strength shows that the fill specimen is elongated more than four times as much as the warp specimen. This elongation would allow the openings formed between adjacent yarns in the fill specimens to be larger than the openings formed in correspondingly loaded warp specimens and therefore a larger measured air permeability for the fill specimen results.

Comparison of the stress-unit elongation curves for the cycled warp specimens with the noncycled warp specimen (see fig. 7) indicates that the initial slopes are about the same; however, for the cycled specimens the linear portion extends to approximately 0.60 of the fabric strength for both specimens. The slopes of the two fill specimens (see fig. 8) which were cyclic loaded are approximately equal at every load but the initial slopes of these curves are about three times greater than the initial slope of the noncycled fill specimen. However, it should be noted that the initial slope of all fill specimen stress-unit elongation curves is less than that of the corresponding warp specimens. The flagged symbols shown in figures 7 and 8 correspond to the stress at which photomicrographs were taken of similar warp and fill specimens.

The reason for the air permeability of the cycled fill specimens approaching a similar value whereas the air permeability of the cycled warp specimens increases with increasing load can probably be explained by examination of the photomicrographs of the specimens in the loaded condition. When load is applied to the twisted warp yarns, they experience a greater transverse contraction than the nontwisted fill yarns. This contraction can be seen in the photomicrographs given in figures 9 and 10. Figure 9 shows the results of various loads on three warp specimens and figure 10 shows the results for similar loads on three fill specimens. In figures 9(a) and 10(a) for the zero load condition, the warp (light colored) and fill (darker colored) yarns are shown to have about the same yarn width. However, in every other case the loaded warp yarns in figure 9 are shown to be much narrower than the similarly loaded fill yarns in figure 10. This condition is particularly true for the cyclic-loaded specimens. In fact, examination of figures 10(b) and 10(c) indicates very little transverse contraction occurs for the loaded fill yarns after cycling. Therefore, the porosity of the warp specimen increases as a result of the transverse contraction and elongation of the warp yarns whereas the porosity of the cycled fill specimen increases as a result of elongation of the fill yarns.

CONCLUDING REMARKS

The air permeability at 0.5 in. H_2O (124 N/m^2) of a particular lightweight fluorocarbon rubber-coated high-temperature nylon fabric subjected to uniaxial tensile loads at room temperature as obtained from strip specimens have been presented. The results demonstrate that the coating remains effective with regard to air permeability for stresses to about 0.90 of the ultimate fabric strength for the initial tensile loading for both the warp and fill directions. However, the coating became ineffective for the specimens subjected to cyclic tensile loads and the resulting air permeability was shown to be dependent on both the magnitude and the number of cyclic loadings. The air permeability of the cyclic-loaded specimens was shown to be different in the warp and fill directions and the differences are attributed to basic differences in the stress-elongation behavior as well as to differences in the yarn twist for the warp and fill directions.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., June 9, 1970.

APPENDIX

CONVERSION OF U.S. CUSTOMARY UNITS TO SI UNITS

Factors required for converting the units used herein to the International System of Units (SI) are given in the following table:

Physical quantity	U.S. Customary Unit	Conversion factor (*)	SI Unit (**)
Area	ft^2	9.29×10^{-2}	meters^2 (m^2)
Force/Length	lbf/in.	1.751×10^2	newtons/meter (N/m)
Length	in.	2.54×10^{-2}	meters (m)
Mass/Area	ozm/yd^2	3.39×10^{-2}	kilograms/meter^2 (kg/m^2)
Pressure	in. H_2O	2.488×10^2	newtons/meter^2 (N/m^2)
Temperature	^oF	(5/9)(F + 459.67)	Kelvin (K)
Velocity	in./min	4.233×10^{-4}	meters/second (m/s)
Volume/Time (flow rate)	ft^3/min	4.719×10^{-4}	meters^3/second (m^3/s)

*Multiply value given in U.S. Customary Unit by conversion factor to obtain equivalent value in SI Units.

**Prefixes to indicate multiples of units are as follows:

Prefix	Multiple
kilo (k)	10^3
deci (d)	10^{-1}
centi (c)	10^{-2}
milli (m)	10^{-3}
micro (μ)	10^{-6}

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TABLE I.- DETAILS OF VITON COATED NOMEX FABRIC

Yarn	100 denier Nomex
Weave	Plain (heat calendered)
Mass of fabric, ozm/yd^2 (kg/m^2)	1.86 (0.06)
Mass of viton coating, ozm/yd^2 (kg/m^2)	0.5 (0.02)
Warp count, yarns/in. (yarns/cm)	81 (32)
Fill count, yarns/in. (yarns/cm)	75 (30)
Warp tensile strength, lbf/in. (kN/m)	83 (14.5)
Fill tensile strength, lbf/in. (kN/m)	77 (13.5)

TABLE II.- AIR PERMEABILITY RESULTS FOR A COATED FABRIC

[Warp specimens]

(a) U.S. Customary Units

$\frac{N_w}{N_{wu}}$	Air permeability, P, ft^3/min/ft^2, for –																			
	No cycling		$\frac{N_{wc}}{N_{wu}} = 0.25$						$\frac{N_{wc}}{N_{wu}} = 0.50$						$\frac{N_{wc}}{N_{wu}} = 0.75$					
			10 cycles			100 cycles			10 cycles			100 cycles			10 cycles			100 cycles		
0	0	0	0	0	0	0	0	0	3.6	8.1	4.9	28.9	22.1	17.3	26.4	28.7	52.5	70.0	67.0	60.0
.20	0	0	0	0	0	0	0	0	9.0	19.4	12.8	43.0	36.6	33.1	36.7	42.2	53.0	84.0	79.0	76.0
.40	0	0	0	0	0	1.4	2.4	1.4	13.7	28.4	19.1	48.0	41.0	42.5	46.0	47.0	64.0	98.0	90.0	87.0
.60	0	0	0	0	0	8.1	9.7	7.1	18.6	37.0	26.6	56.0	49.0	46.0	50.0	58.0	79.0	111.0	108.0	102.0
.70	0	0	0.7	3.6	0	12.5	---	---	21.8	---	---	----	----	53.0	55.0	65.0	83.0	116.0	114.0	109.0
.80	0	0	2.6	10.3	0	17.4	23.9	16.7	28.4	53.0	43.0	85.0	79.0	70.0	60.0	72.0	87.0	122.0	118.0	116.0
.90	0	0	13.4	35.4	0	30.9	---	27.8	42.2	82.0	67.0	111.0	115.0	109.0	65.0	101.0	92.0	134.0	127.0	121.0
.94	1.4	1.5	---	---	-	---	---	---	---	---	---	----	----	----	---	----	---	----	----	----
.98	3.0	3.1	---	---	-	---	---	---	---	---	---	----	----	----	---	----	---	----	----	----
1.00	6.5	6.5	---	---	-	---	---	---	---	---	---	----	----	----	---	----	---	----	----	----

(b) S. I. Units

$\frac{N_w}{N_{wu}}$	Air permeability, P, dm^3/s/m^2, for –																			
	No cycling		$\frac{N_{wc}}{N_{wu}} = 0.25$						$\frac{N_{wc}}{N_{wu}} = 0.50$						$\frac{N_{wc}}{N_{wu}} = 0.75$					
			10 cycles			100 cycles			10 cycles			100 cycles			10 cycles			100 cycles		
0	0	0	0	0	0	0	0	0	18.3	41.1	24.9	146.8	112.2	87.9	134.1	145.8	266.6	355.5	340.3	304.7
.20	0	0	0	0	0	0	0	0	45.7	98.5	65.0	218.4	185.9	168.1	186.4	214.3	269.2	426.6	401.2	386.0
.40	0	0	0	0	0	7.1	12.2	7.1	69.6	144.2	98.5	243.8	208.2	215.8	233.6	238.7	325.0	197.7	457.1	441.8
.60	0	0	0	0	0	41.1	49.3	36.1	94.5	187.9	135.1	284.4	248.8	233.6	253.9	294.6	401.2	563.7	548.5	518.0
.70	0	0	3.6	18.3	0	63.5	----	----	110.7	----	----	----	----	269.2	279.3	330.1	421.5	589.1	578.9	553.6
.80	0	0	13.2	52.3	0	88.4	121.4	84.8	144.2	269.2	218.4	431.7	401.2	355.5	304.7	365.6	441.8	619.6	599.3	589.1
.90	0	0	68.1	179.8	0	156.9	----	141.2	214.3	416.4	340.3	563.7	584.0	553.6	330.1	528.2	467.2	680.5	645.0	614.5
.94	7.1	7.6	---	----	-	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
.98	15.2	15.7	---	----	-	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
1.00	33.0	33.0	---	----	-	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----

TABLE III.- AIR PERMEABILITY RESULTS FOR A COATED FABRIC

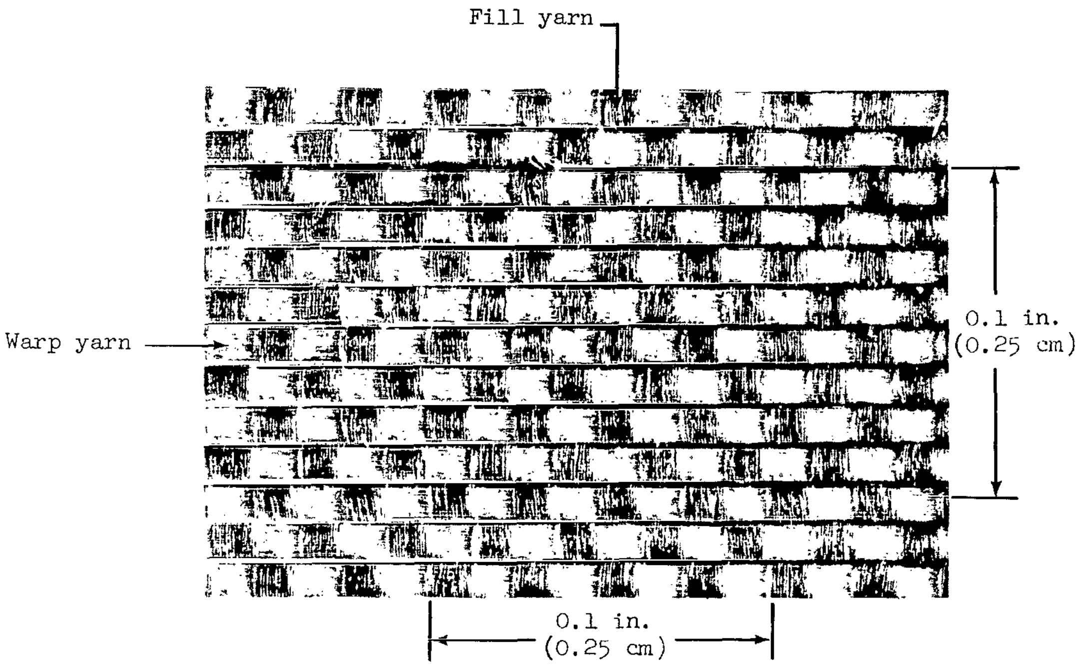
[Fill specimens]

(a) U.S. Customary Units

$\frac{N_f}{N_{fu}}$	Air permeability, P, $ft^3/min/ft^2$, for –																			
	No cycling		$\frac{N_{fc}}{N_{fu}} = 0.25$						$\frac{N_{fc}}{N_{fu}} = 0.50$						$\frac{N_{fc}}{N_{fu}} = 0.75$					
			10 cycles			100 cycles			10 cycles			100 cycles			10 cycles			100 cycles		
0	0.	0	0	2.4	0.7	6.5	15.9	10.0	14.9	12.8	7.8	35.3	32.0	43.0	35.6	49.0	46.2	50.0	60.0	50.2
.22	0	0	.2	7.5	3.6	8.1	19.4	12.8	16.1	13.7	9.0	34.2	30.9	40.0	33.5	46.0	43.6	48.0	56.0	46.0
.43	0	0	1.4	14.2	8.5	12.1	25.6	17.6	19.1	16.1	10.2	36.4	32.6	43.0	35.4	48.0	46.0	50.0	57.0	47.9
.65	0	0	11.8	28.1	21.2	25.8	39.4	29.9	25.6	21.2	15.6	40.6	38.3	46.0	38.5	51.0	50.5	55.0	60.0	50.9
.76	0	0	15.9	---	---	34.8	---	---	36.1	27.0	20.9	46.5	44.1	51.0	39.9	54.0	53.7	57.0	61.0	53.7
.87	0	0	23.2	46.0	34.2	42.8	55.0	46.5	49.0	34.8	42.2	53.0	49.0	61.0	43.0	57.0	57.0	59.0	64.0	57.0
.97	1.4	2.6	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---

(b) S. I. Units

$\frac{N_f}{N_{fu}}$	Air permeability, P, $dm^3/s/m^2$, for –																			
	No cycling		$\frac{N_{fc}}{N_{fu}} = 0.25$						$\frac{N_{fc}}{N_{fu}} = 0.50$						$\frac{N_{fc}}{N_{fu}} = 0.75$					
			10 cycles			100 cycles			10 cycles			100 cycles			10 cycles			100 cycles		
0	0	0	0	12.2	3.6	33.0	80.8	50.8	75.7	65.0	39.6	179.3	162.5	218.4	180.8	248.8	234.6	253.9	304.7	254.9
.22	0	0	1.0	38.1	18.3	41.1	98.5	65.0	81.8	69.6	45.7	173.7	156.9	203.1	170.1	233.6	221.4	243.7	284.4	233.6
.43	0	0	7.1	72.1	43.2	61.5	130.0	89.4	97.0	81.8	51.8	184.9	165.6	218.4	179.8	243.8	233.6	253.9	289.5	243.3
.65	0	0	59.9	142.7	107.7	132.0	200.1	151.8	130.0	107.7	79.2	206.2	194.5	233.6	195.5	259.0	256.5	279.3	304.7	258.5
.76	0	0	80.8	----	----	176.7	----	----	183.3	137.1	106.1	236.2	223.9	259.0	202.6	274.2	272.7	289.5	309.8	272.7
.87	0	0	117.8	233.6	173.7	217.4	279.3	236.2	248.8	176.7	214.3	269.2	248.8	309.8	218.4	289.5	289.5	299.6	325.0	289.5
.97	7.1	13.2	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----



L-70-4720

Figure 1.- Photomicrograph of coated fabric.

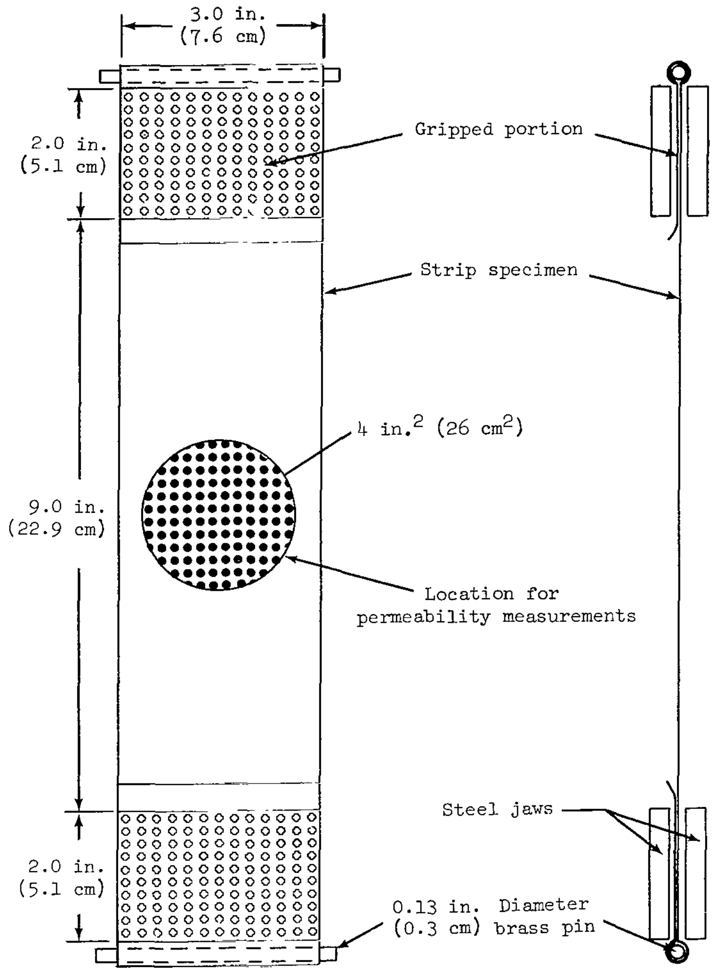


Figure 2.- Details of test specimen and method of gripping.

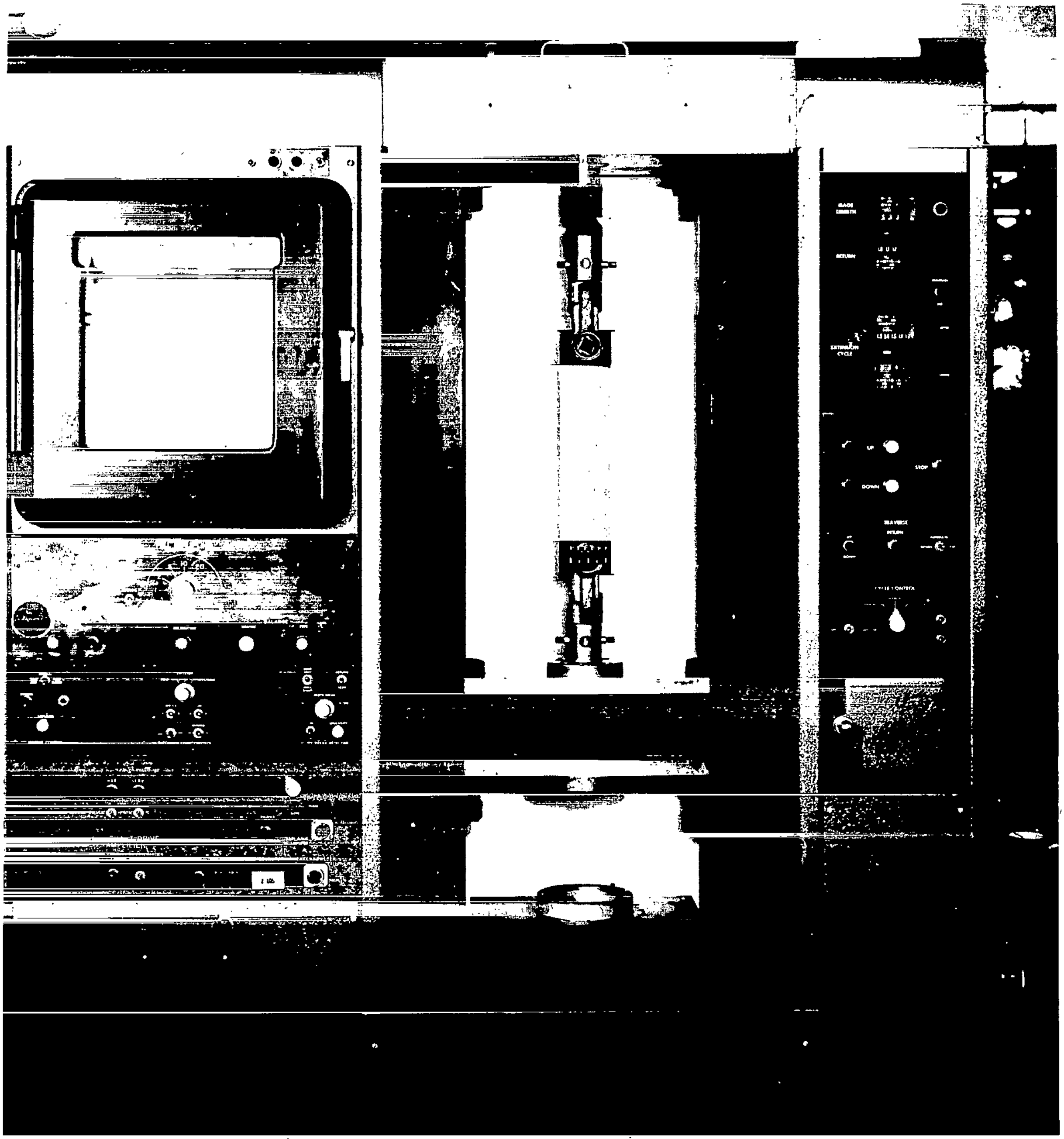


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Figure 3.- Test setup for static and cyclic tensile loading of fabric strip specimens.

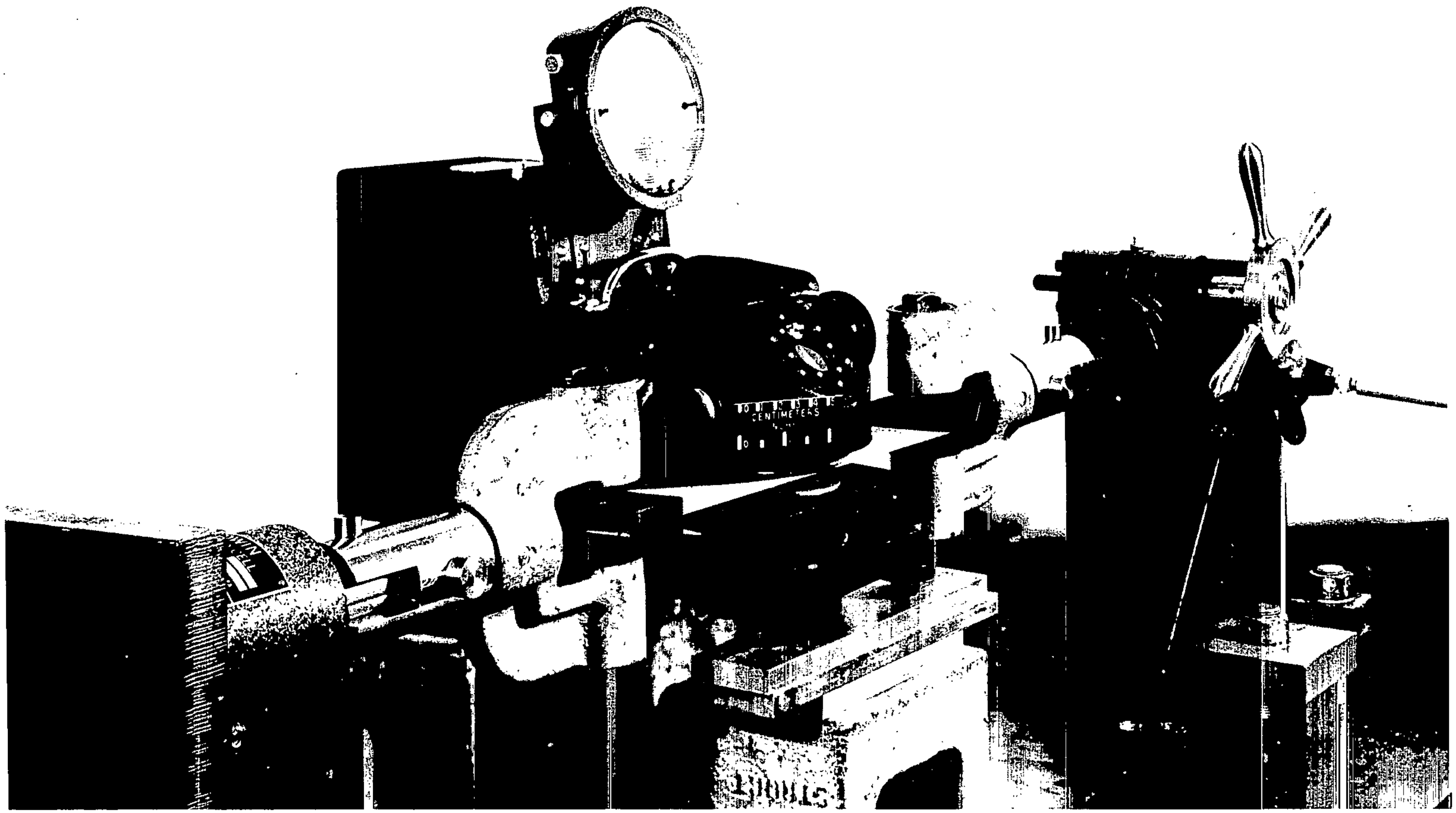

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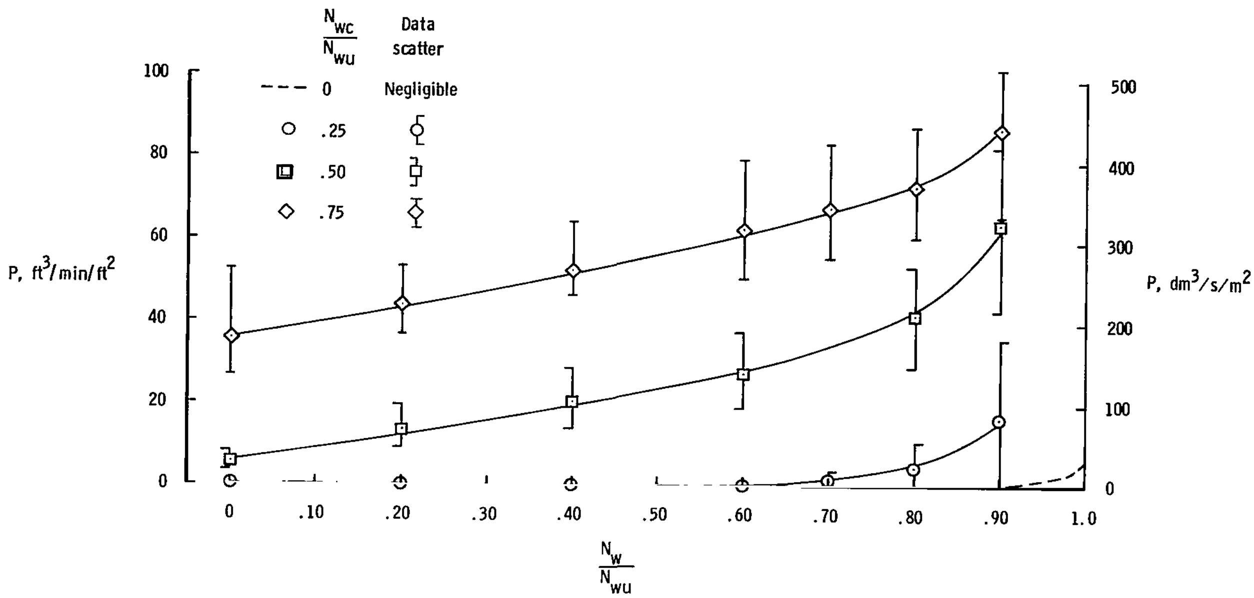
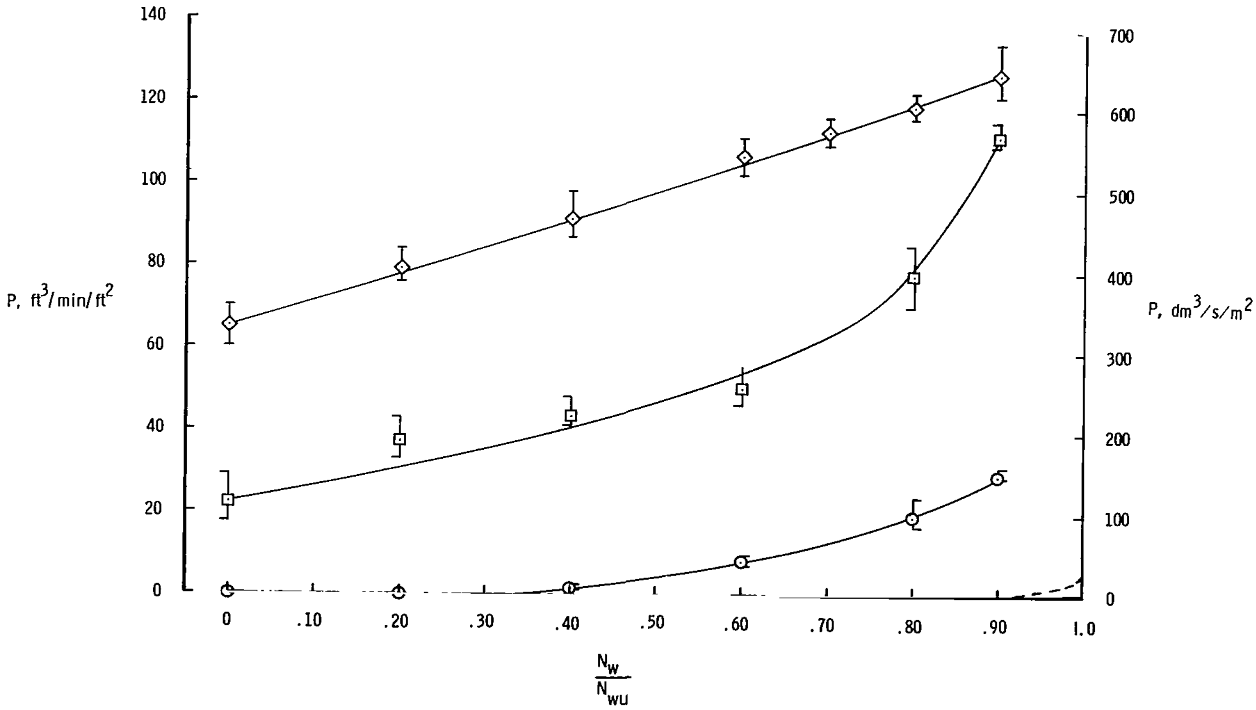
Figure 4.- Test setup for measuring air permeability of fabric strip specimens while subjected to uniaxial tension.

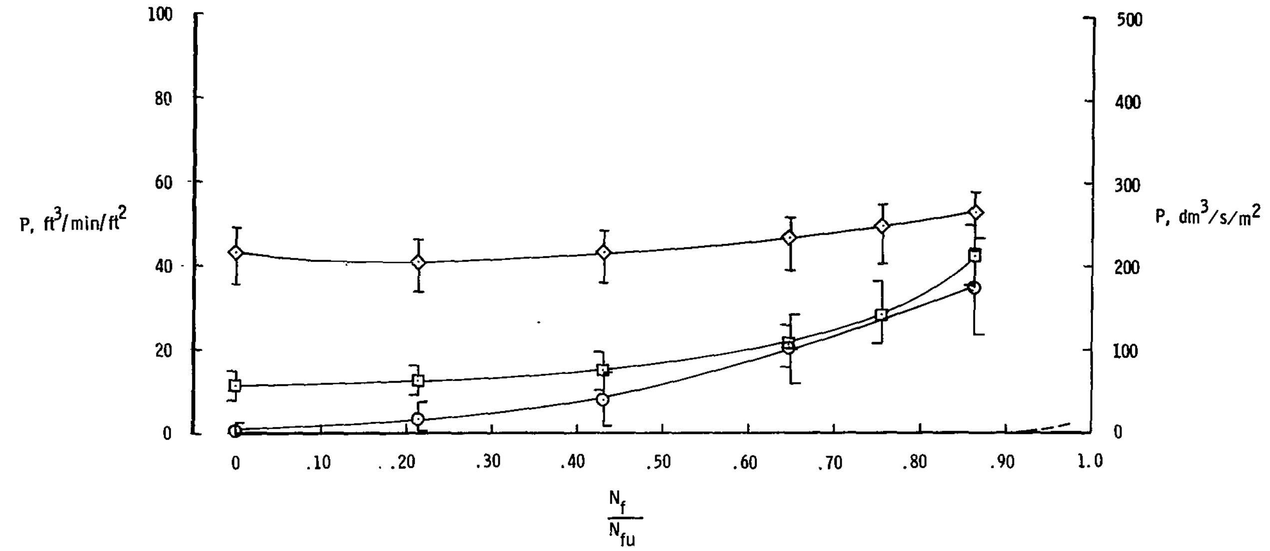


(a) 10 cycles.

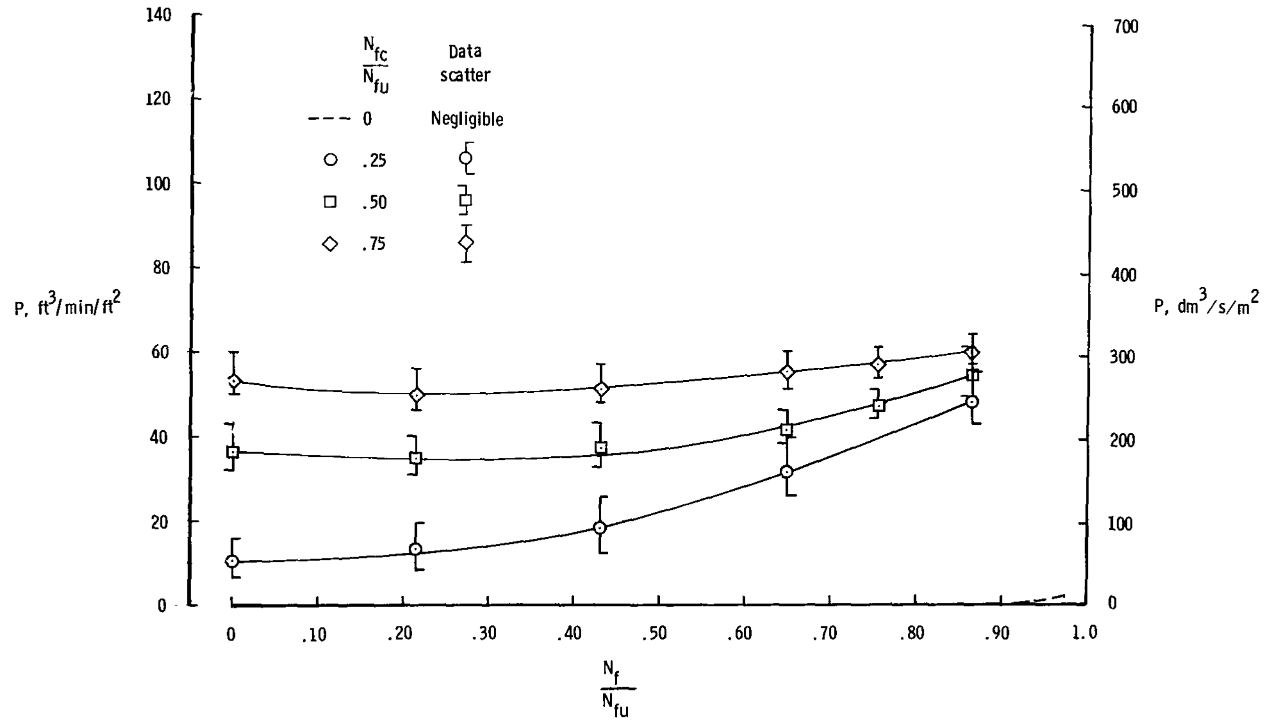


(b) 100 cycles.

Figure 5.- Effects of uniaxial tensile loads and load cycling on the air permeability of a lightweight coated fabric. Warp specimens.



(a) 10 cycles.



(b) 100 cycles.

Figure 6.- Effects of uniaxial tensile loads and load cycling on the air permeability of a lightweight coated fabric. Fill specimens.

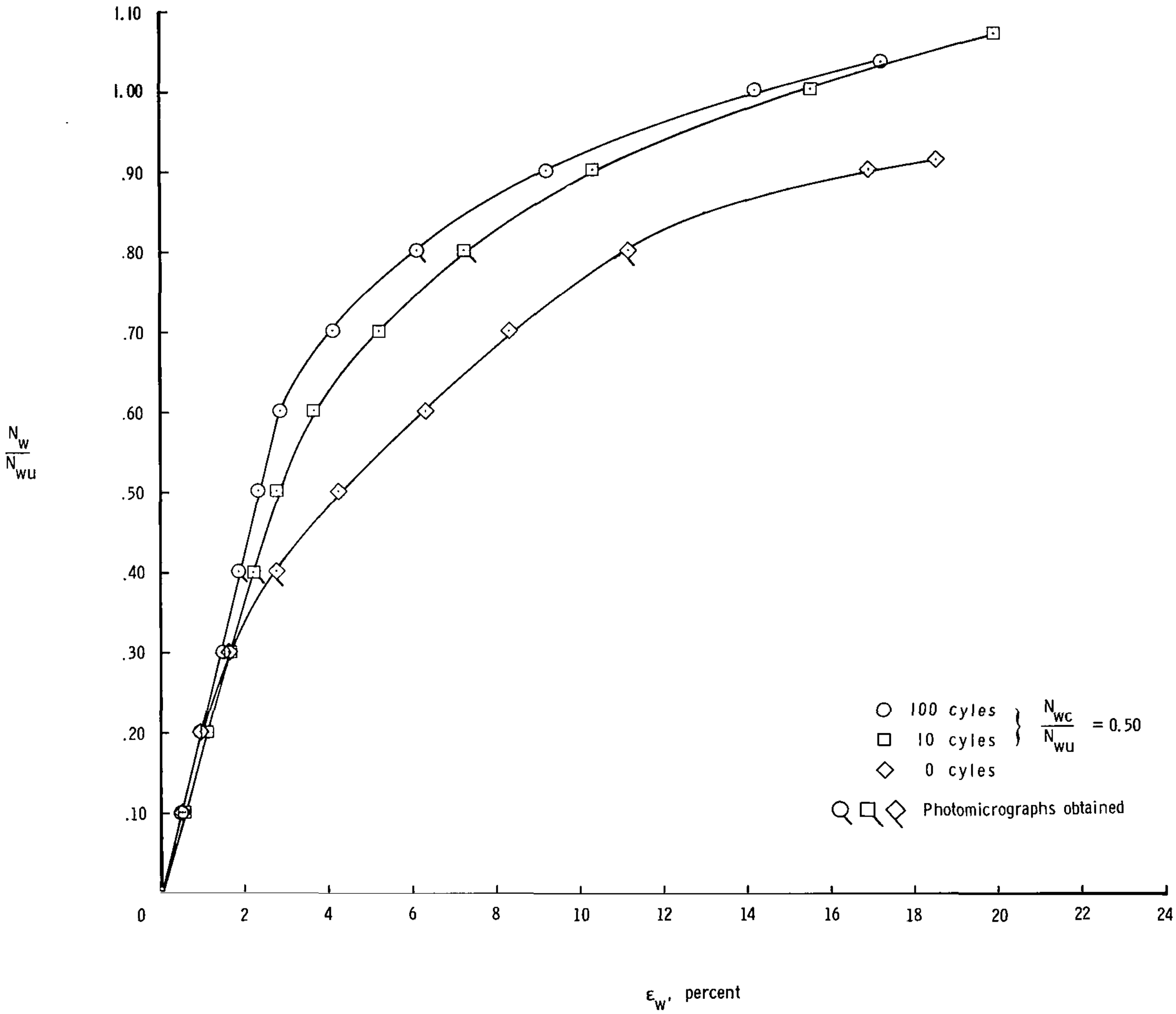


Figure 7.- Typical stress-unit elongation curves for cycled and noncycled warp specimens.

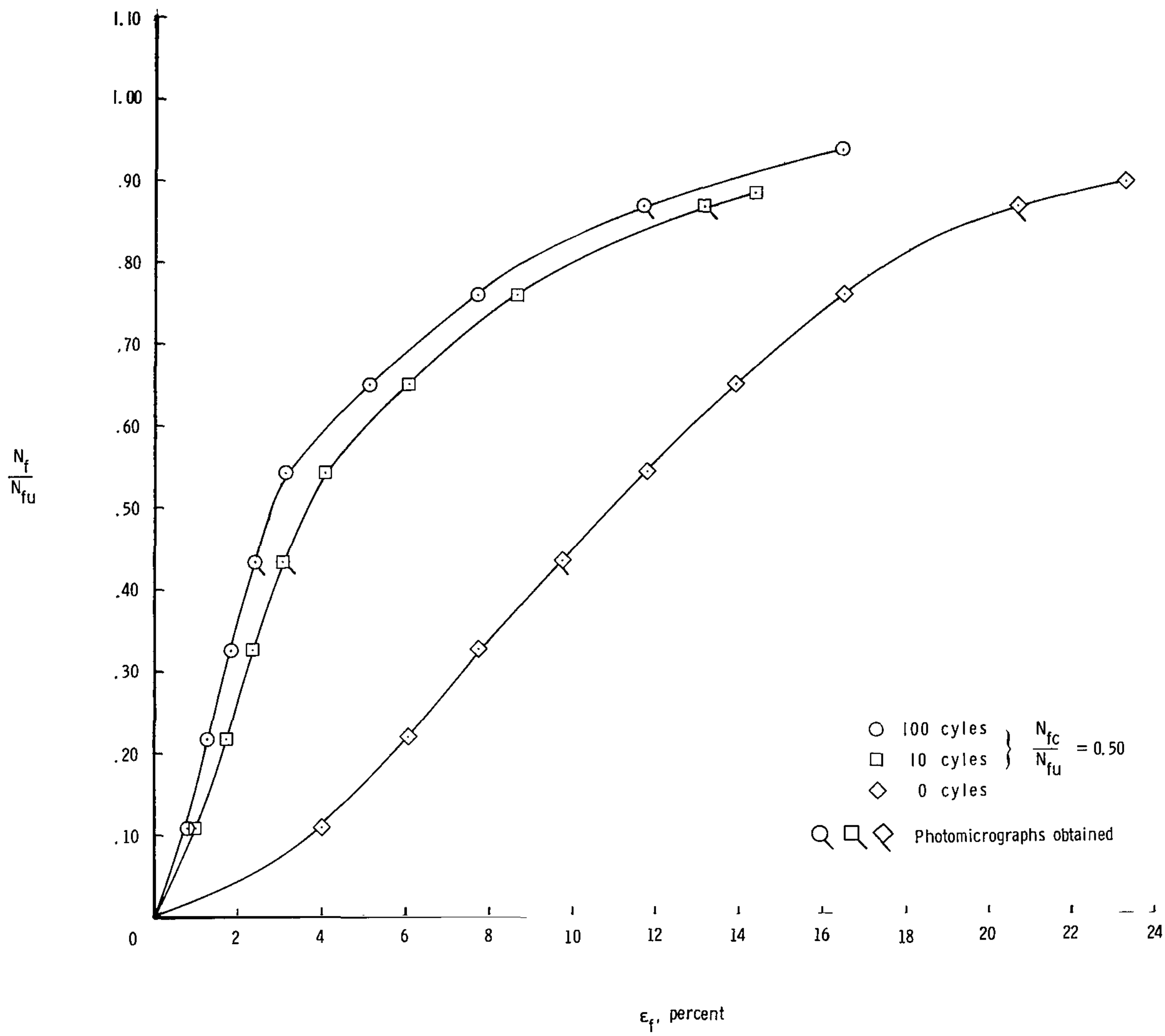
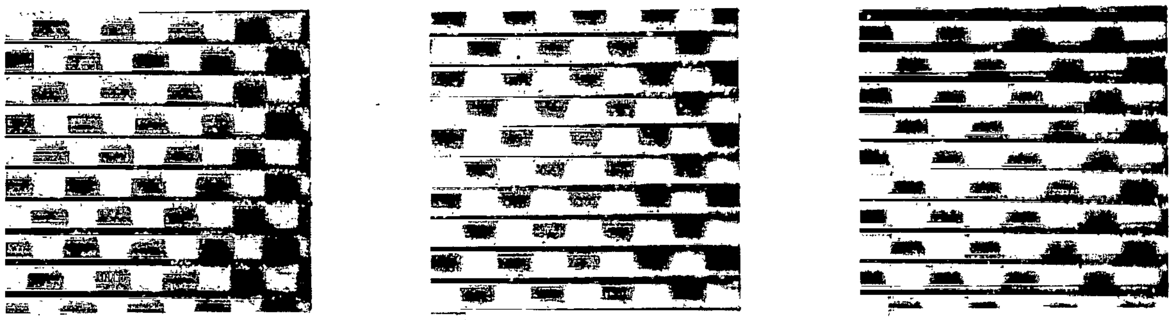


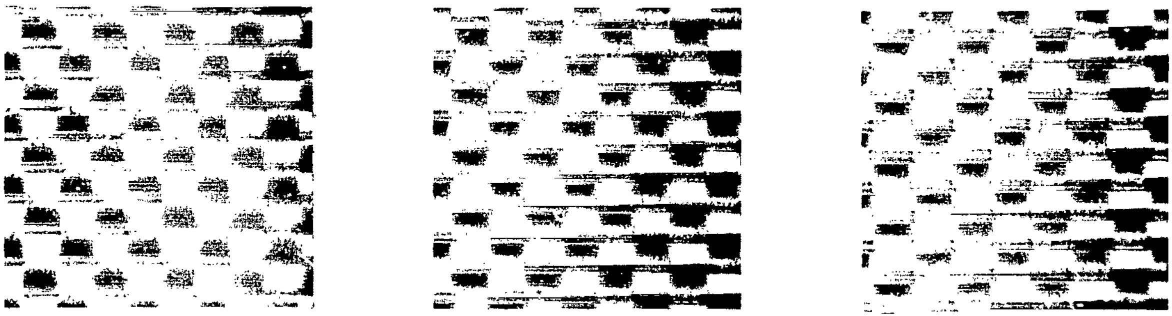
Figure 8.- Typical stress-unit elongation curves for cycled and noncycled fill specimens.

Direction of warp yarns and applied load



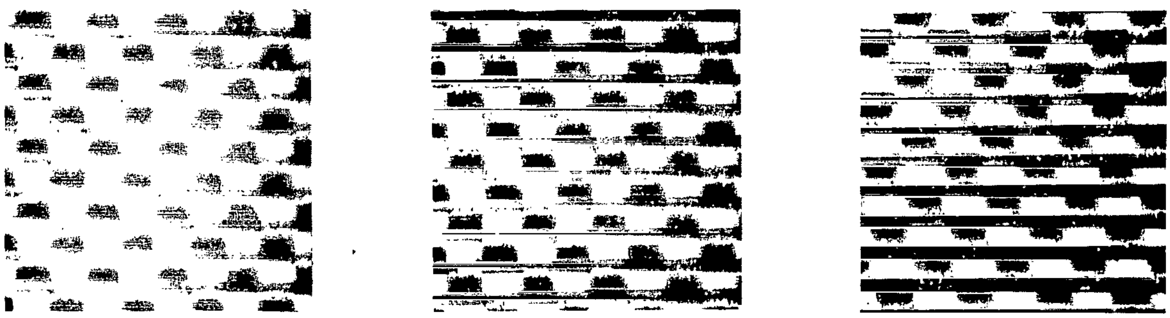
$\frac{N_w}{N_{wu}} = 0$ $\frac{N_w}{N_{wu}} = 0.40$ $\frac{N_w}{N_{wu}} = 0.80$

(a) $\frac{N_{wc}}{N_{wu}} = 0.$



$\frac{N_w}{N_{wu}} = 0$ $\frac{N_w}{N_{wu}} = 0.40$ $\frac{N_w}{N_{wu}} = 0.80$

(b) $\frac{N_{wc}}{N_{wu}} = 0.50$; 10 cycles.



$\frac{N_w}{N_{wu}} = 0$ $\frac{N_w}{N_{wu}} = 0.40$ $\frac{N_w}{N_{wu}} = 0.80$

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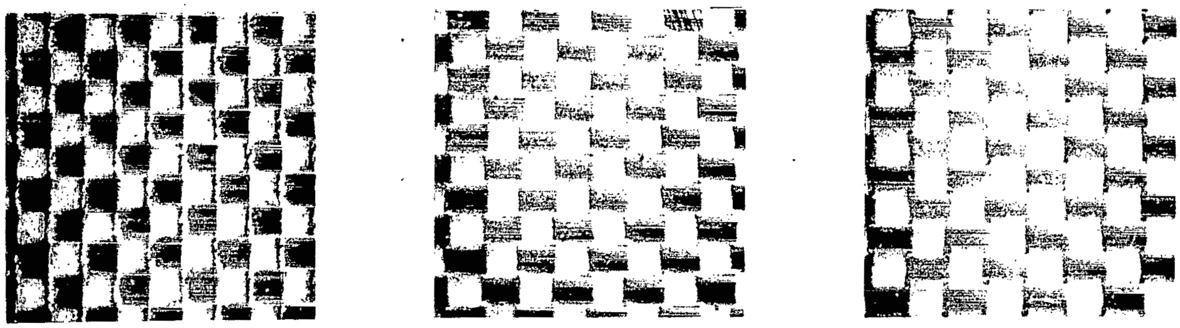
(c) $\frac{N_{wc}}{N_{wu}} = 0.50$; 100 cycles.

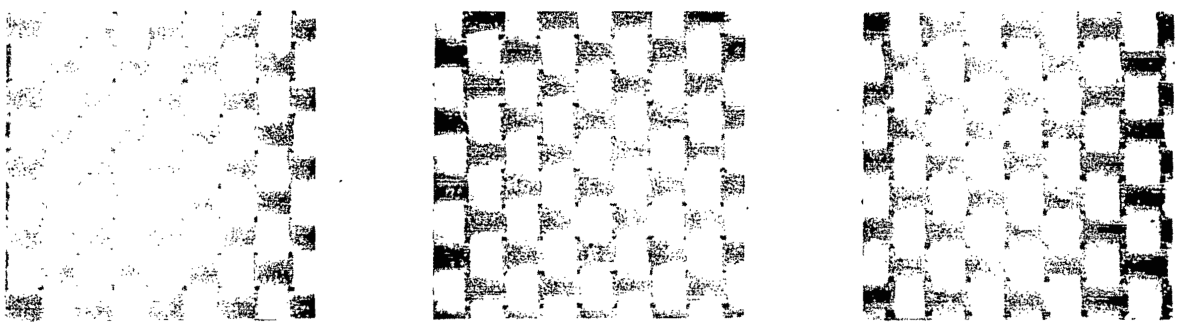
gure 9.- Photomicrographs of warp specimens subjected to various loading conditions.

← Direction of fill yarns and applied load →



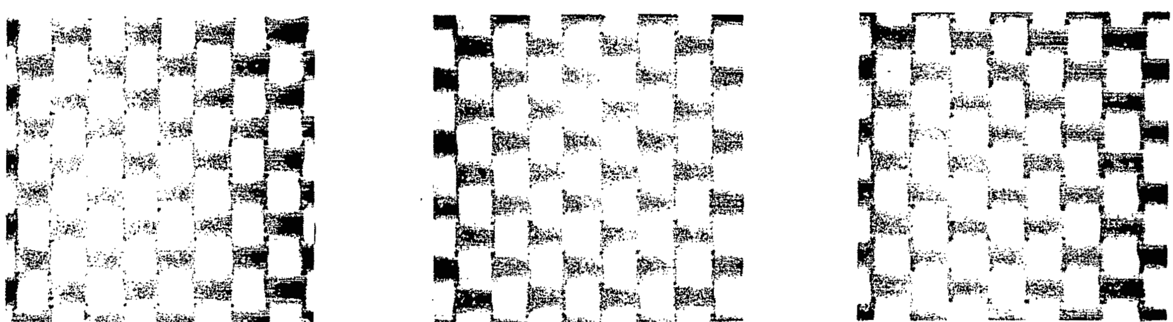
$\frac{N_f}{N_{fu}} = 0$ $\frac{N_f}{N_{fu}} = 0.43$ $\frac{N_f}{N_{fu}} = 0.87$

(a) $\frac{N_{fc}}{N_{fu}} = 0.$



$\frac{N_f}{N_{fu}} = 0$ $\frac{N_f}{N_{fu}} = 0.43$ $\frac{N_f}{N_{fu}} = 0.87$

(b) $\frac{N_{fc}}{N_{fu}} = 0.50$; 10 cycles.



$\frac{N_f}{N_{fu}} = 0$ $\frac{N_f}{N_{fu}} = 0.43$ $\frac{N_f}{N_{fu}} = 0.87$

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(c) $\frac{N_{fc}}{N_{fu}} = 0.50$; 100 cycles.

Figure 10.- Photomicrographs of fill specimens subjected to various loading conditions.

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